Alleviating the water scarcity in the Huang-Huai-Hai region: the role of virtual water and real water transfer

Abstract

The Huang-Huai-Hai (3H) region is the most water scarce region in China. Its regional water security is closely relevant to interregional water movement, which can be realized by real water transfers through massive engineering projects and/or by virtual water transfers in form of commodity trade. This study conducts an interregional input-output analysis to investigate the roles of virtual water trade and real water transfer in coping with its regional water crisis based on China Interregional Input-Output model 2007. The results show that the 3H region as a whole is receiving approximately 3 billion m^3/year of net virtual water from outside. Its virtual water inflow is dominated by the agricultural sector from other provinces, 166 billion m^3/year and its virtual water export is dominated by manufacturing sectors to other countries, 117 billion m^3/year. Both virtual water import and real water transfer from South to North Water Diversion (SNWD) project are important water supplements in alleviating the water pressure in the 3H region, especially for Beijing and Tianjin which have severe water deficit. This study also points out that the 3H region will retain its role as the major producer of wheat and maize due mainly to favorable climate conditions, making the water use efficiency improvement in irrigation crucially important for reducing the internal water use, hence the pressure on its water resources. The results of this study provide useful scientific references for the establishment of combating strategies to deal with water scarcity in the future.

1. Introduction

The Huang-Huai-Hai (3H) region in China is currently standing in-between the prosperous economic growth and the severe water crisis. Its important economic role in the nation can be easily seen through statistics: In 2012, its GDP amounted to 12.4 trillion Yuan (1 Yuan ≈ 0.16 USD), equivalent to around 25% of the whole nation.

Its industrial value-added amounted to 44% of the region's GDP, reflecting its high level of industrialization (NBSC, 2013). However, its water resources condition is mismatched with the economic development. The region possesses less than 10% of the nation's water resources. The average per capita water resource is 330 m^3, less than 1/5 of the water scarcity threshold of 1700 m^3, defined by Falkenmark (1995). According to China Water Resources Bulletin, the ratio of the total annual water withdrawal to total annual water resources in the 3H region is about 74%. The situation in the Haihe basin is particularly serious, where the water withdrawal exceeds the renewable water resources by 23% (The Ministry of Water Resources of China, 2011), indicating the mining of non-renewable ground water. Besides, the 3H region is dominated by the continental temperate monsoon climate which is characterized by unevenly distributed precipitation within a year, making the water scarcity even more severe in dry seasons. Water shortage is becoming bottleneck to the sustainable development in the 3H region.

The water crisis in the 3H region has drawn much attention in China. A series of measures have been implemented to save the 3H region from the water crisis. The South-to-North Water Diversion (SNWD) project is one of these measures. The basic conception of the project is to "borrow" some water from the water-rich South China to the water-scarce North China. The first phase of the project is to be complete in 2014. The project is envisaged to alleviate the water pressure in North China, provide water for the rehabilitation of the degraded ecosystems, and secure a balanced development for the whole nation (Liu and Zheng, 2002; Berkoff, 2003; Gu, et al., 2012).

In contrast to the visible "real" water transfer by the SNWD project, a sort of invisible or "hidden" water movement also takes place between the 3H region and the rest of the country as well as the other countries. That is virtual water, the water used for the production of goods and services (Allan, 1993; Yang et al., 2006). The concept of virtual water provides an additional perspective to view the relationship between economic activities and use of natural resources. As one of the economic hubs in China, the 3H region is closely connected with other regions (and countries) through trade of goods and services. The virtual water embodied in these goods and services can bring along significant impacts on the water resources condition of the 3H region.

There have been many studies about the water transfer issue in China. In these studies, the “real water” and “virtual water” are usually separately discussed. For the “real water” transfer, studies have been mainly debating on the controversial impact of implementing the SNWD project. On the positive side, the SNWD project can effectively increase the water supply of the recipient areas, conducive to halting the deterioration of ground water over-exploitation and thus is beneficial to the social-economic development (Feng et al., 2007; Ma and Zheng, 2010; Yang et al, 2012). On the negative side, however, the project can bring along risks to the environment and ecosystem (Yang and Zehnder, 2005; Zhang, 2009; Dong et al., 2011; Gu et al., 2012). Besides, the conflicts in water resources management in the post-transfer stage (i.e. the defining of the water right, the establishment of water allocation rules, the supervision on the water trade system, etc.) have also drawn extensive concern (Wei et al., 2010; Chang et al., 2011; Chen et al., 2013). As for the virtual water transfer, previous studies have mainly focused on the virtual water flows across regions, economic sectors, and their role in addressing water scarcity and redistributing water resources (Yang and Zehnder, 2002; Hoekstra and Hung, 2005; Huang and Xia, 2005; Yang et al., 2006; Hoekstra and Chapagain, 2007; Fang et al, 2010; Feng et al., 2012; Sun et al, 2013). The application of input-output tables, a quantitative model representing the monetary transactions of goods and services among different sectors throughout economic system, has enabled a systematic assessment of virtual water flows across all the sectors in an economic system (Guan and Hubacek, 2007; Dietzenbacher and Velazquez, 2007; Lenzen, 2009; Wang and Wang, 2009; Yang et al., 2010; Zhao et al., 2010; Zhang et al., 2011; Lin et al, 2012). So far, the literature conducting a comprehensive analysis incorporating both real and virtual water into consideration is rare.

This paper investigates the roles of real water and the virtual water transfers in the 3H region and addresses the implications for dealing with regional water crisis. The research questions include: 1) **What is the pattern of virtual water flows in the**

<u>3H region?</u> The analysis focuses on two aspects. One is the quantification of the virtual water flows between the 3H region and the other regions of the country as well as with other countries (i.e. How much virtual water flows out of and into the region?). The other is the sectoral characteristic of the virtual water flows of the region. 2) **<u>What roles do the virtual water flows and real water transfer from the SNWD project respectively play in dealing with water scarcity in the 3H region</u>**? More precisely, has the movement of virtual water been in favor of reducing the water pressure in the 3H region, or on the contrary? To what extent can the water pressure in the 3H region be alleviated by the SNWD project?

2. Methodology and data

2.1 Data

Interregional input-output table

The quantitative analysis in this study is based on China Interregional Input-output 2007 (China-IRIO 2007), which was built by the main authors of this paper (Shi and Zhang, 2012.). China-IRIO 2007 consists of 30 administrative entities including 22 provinces, 4 municipalities and 4 autonomous regions in mainland China. Hong Kong, Macao, Taiwan and Tibet are not included due to data unavailability. For simplicity, these 30 administrative entities are all called provinces in this study. The standard structure of China-IRIO 2007 is shown in Table 1. Considering the sector concordance between interregional input-output tables and the data of sectoral direct freshwater use, the 60 sectors in the tables are aggregated into 29 sectors in this study (Table 2).

Table1. The standard format of China-IRIO 2007

<table>
<tr><th colspan="3" rowspan="3">Output
Input</th><th colspan="7">Intermediate consumption</th><th>Final consumption</th><th rowspan="3">Export</th><th rowspan="3">Import</th><th rowspan="3">Error</th><th rowspan="3">Total output</th></tr>
<tr><th colspan="3">R_1</th><th>…</th><th colspan="3">R_{30}</th><th rowspan="2">R_1… R_{30}</th></tr>
<tr><th>s_1</th><th>…</th><th>s_{60}</th><th>…</th><th>s_1</th><th>…</th><th>s_{60}</th></tr>
<tr><td rowspan="3">Intermediate input</td><td rowspan="3">R_1</td><td>s_1</td><td colspan="7" rowspan="3">x_{ij}^{RS}</td><td rowspan="3">f_{it}^{RS}</td><td rowspan="3">E_i^R</td><td rowspan="3">M_i^R</td><td rowspan="3">ERR_i^R</td><td rowspan="3">X_i^R</td></tr>
<tr><td>…</td></tr>
<tr><td>s_{60}</td></tr>
</table>

	…	…							
	R_{30}	s_1							
		…							
		s_{60}							
Added value			v_{hj}^{S}						
Total input			X_{j}^{S}						

Geographically, the administrative area of the 3H region includes Beijing, Tianjin, Shandong, the majority of Hebei, Henan and a minor share of Jiangsu and Anhui. In this study, the area of the 3H region is defined as the total area of Beijing, Tianjin, Shandong Hebei and Henan, with Jiangsu and Anhui not included. The omission of the two provinces is resulted from the feature of input-output table the provinces of which are requested to be complete administrative entities. Since the share of Jiangsu and Anhui involved in the 3H region is quite limited, including the two whole provinces may make the study area deviated from reality and derive misleading results. In the analysis of virtual water trade pattern, the 30 provinces are classified into eight regions taking into consideration their geographic locations, the river basins they pertain to, and the economic clusters they involved in. The geographic distribution of the eight regions and information of their water resources conditions are demonstrated in Figure 1. There are four regions having the water resources per capita lower than the water scarcity threshold of 1700 m^3/capita: the 3H region, the Northeast, the East Coast and the Central, and the water scarcity situation of the 3H region is the most severe.

Figure 1. The administrative area and water resources conditions of the eight regions

The data of water resources per capita (WR/cap) are the average values of 2002–2008 (NBSC, 2003-2009).

Data for virtual water accountings and SNWD project

In the virtual water accounting, the data of direct water use coefficient (DWUC), the amount of direct water intake to produce one monetary unit of output, are obtained based on Sectoral Water Requirement Quotas of the 30 provinces (The Ministry of Water Resources of China, 2006). In order to ensure data reliability, the data are further calibrated to keep the total amount of water consumption of primary sectors, secondary sectors and tertiary sectors consistent with the data from the provincial Water Resource Bulletins (Water Authority of 30 provinces, 2002 and 2007).

In this study, the water use refers to the use of surface and ground water in economic activities, with soil moisture not included. Considering the possibility of reutilization without treatment, the return flow of the agricultural sectors is deducted from the total sectoral water use, whereas the wastewater discharge is not deducted from the industrial water use. The detailed explanations on these treatments are elaborated in Zhang et al., 2012.

The SNWD project is the largest inter-basin water transfer project ever implemented in the world, with three routes (East route, Middle route, and West route), stretching more than 1,000 km across the east, middle, and west parts of China. The project is planned to be fully completed by 2050 and will be capable of transferring a total water of 44.8 billion m^3, including 14.8 billion m^3 in East Route, 13 billion m^3 in Middle Route and 17 billion m^3 in West Route. The first phase of the project is to be completed in 2014 and about 10.9 billion m^3 of water will be delivered to the 3H region. The detail of the allocation of the first phase water transfer among the 3H provinces is provided in Table 3.

2.2 Methodology

The basic mathematical structure of the interregional input-output model

The interregional input-output table is a top-down economic model. It uses interregional and inter-sectoral monetary transaction data to account for the interconnections of different industries in different regions. Assuming the number of regions is n, and for each region there are m sectors, then the mathematical structure of an interregional input-output system consists of ($m \times n$) linear equations. They show the contribution of the production of one sector of one region to the intermediate and final consumption of all the sectors of all the regions in the form of monetary transactions of goods and services. The standard interregional input-output model is represented by Eq.1

$$X^R = A^{RS}X^R + F^{RS} \qquad (1)$$

where X^R is the output matrix of region R; A^{RS} is the matrix of interregional input coefficients, representing the intermediate demand of industries in region S supplied by industries in region R; F^{RS} is the final consumption of region S supplied by region R; E^R and M^R are respectively the export and import of region R.

China-IRIO 2002 and China-IRIO 2007 are characterized as import-competitive, the underlying assumption of which is that the imports are competitive with domestic supplies and hence the imports can be incorporated with domestic supplies in each row. In order to separately account the water embodied in the domestically-produced products, an import coefficient matrix $\widehat{M}$, the proportions of the imported goods in the total demand, is applied to eliminate the imported goods contained in intermediate demand $A^{RS}X^{R}$ and final demand F^{RS}. Then Equation 1 can be rewritten as:

$$X^{R} = \left[I - (I - \widehat{M})A^{RS}\right]^{-1}\left[(I - \widehat{M})F^{RS}\right] \qquad (2)$$

where $\left[\mathrm{I} - (\mathrm{I} - \widehat{\mathrm{M}})\mathrm{A}^{\mathrm{RS}}\right]^{-1}$ is known as the import-excluded Leontief inverse matrix denoting how much output in region *R* is required to meet one monetary unit of the final consumption region *S*.

Interregional virtual water accountings based on interregional input-output model

In order to combine the monetary trade with the associated water use, the essential step is to derive direct water use coefficient (DWUC), the amount of direct water intake to produce one monetary unit of output, representing the direct or the first round effects of the sectoral interaction in the economy (Bouhia, 2001; Hubacek and Sun, 2005). The DWUC of region *R* can be expressed as Eq.3.

$$W^{R} = \left[\omega_j^R\right], \quad \omega_j^R = \frac{w_j^R}{x_j^R} \qquad (3)$$

where W^{R} is the DWUC matrix of region *R* (measured in $m^3/10^4$ Yuan in this study); Its element $\mathrm{w}_{\mathrm{j}}^{\mathrm{R}}$ is the DWUC of sector *j* in region *R*, which can be derived through dividing the water use of sector j in region *R* $\mathrm{w}_{\mathrm{j}}^{\mathrm{R}}$ by total output of sector *j* in region *R* $\mathrm{x}_{\mathrm{j}}^{\mathrm{R}}$.

The matrix of total water use coefficient (TWUC) T^{RS}, (measured in m^3 $/10^4$ Yuan), an indicator of the total water consumption throughout the whole production chain, can be achieved by multiplying DWUC matrix with the Leontief inverse matrix:

$$T^{RS} = W^{RS}\left[I - (I - \widehat{M})A^{RS}\right]^{-1} \qquad (4)$$

$$W^{RS} = \begin{bmatrix} W^{R_1} & 0 & \cdots & 0 \\ 0 & W^{R_2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & W^{R_n} \end{bmatrix} \quad (5)$$

In the end, the interregional virtual water trade can be obtained by multiplying final demand with TWUC:

$$VWT^{RS} = T^{RS}\left[(I - \widehat{M})F^{RS}\right] \quad (6)$$

3. Results

3.1 Virtual water trade pattern of the 3H region

Quantity of the virtual water movement

The net virtual water trade of the eight regions is shown in Figure 2. The volume contains interregional and international net virtual water trade. The former is the net virtual water flows amongst provinces within the national boundary, the latter refers to the trade of the 3H region with other countries outside China. The 3H region is active in both interregional and international trade. It is a receiver of virtual water in the interregional trade, the net virtual water import amounts to 19.4 billion m^3 /year, 44% of the total net interregional virtual water trade. The other two net virtual water receivers are South Coast and East Coast regions. Despite being the most water scarce region, the 3H region has a considerable amount of net virtual water export of 16.4 billon m^3 in the international trade, next to the East Coast as the second largest international virtual water exporter. This loss of virtual water nearly offsets its net virtual water import through interregional trade. In the end, the 3H region only has a net influx of virtual water of 3 billion m^3 /year through trade with other provinces and countries.

The interconnection between the 3H region and other provinces with regard to virtual water is shown in Figure 3. There are 17 provinces being the virtual water providers to the 3H region, with the total amount of 24.4 billion m^3/year. Guangxi, Heilongjiang and Jiangsu are the major virtual water providers, the summation of which is 12.8 billion m^3/year, exceeding 50% of the total. The amount flows out of the

3H region to other provinces is 19.4 billion m^3/year. The main destinations of the virtual water outflow include Shanghai, Zhejiang and Guangdong.

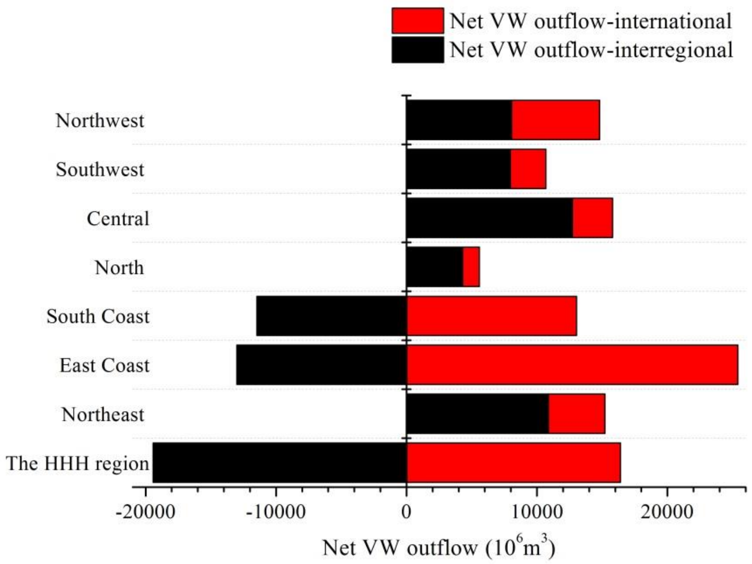

Figure 2. Net virtual water trade of the eight regions (Negative number means net import)

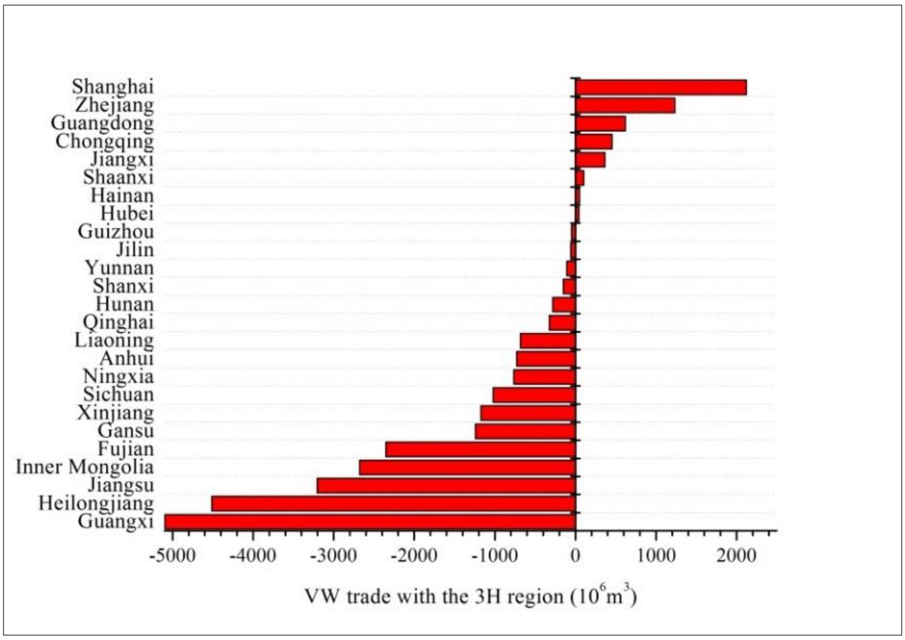

Figure 3. The interregional virtual water trade between the 3H region and other provinces

Sector characteristics of the virtual water flows

The virtual water flows between the 3H region and other provinces and abroad with specification of the sectoral components are shown in Table 2. For visual clarity, the 29 sectors are aggregated to five major categories on the basis of the features of the sectors.

The interregional virtual water trade of the 3H region is dominated by the agricultural products. In general, the 3H region is receiving virtual water from other provinces through agricultural products, accounting for 86% of the total net virtual water inflow of all the sectors. The major agricultural virtual water providers for the 3H region include Guangxi, Heilongjiang, Jiangsu and Inner Mongolia and their total agricultural virtual water flow to the 3H region is 14.7 billion m^3/ year, accounting for 88% of the total agricultural virtual water net inflow to the 3H region. On the other hand, the 3H region is exporting virtual water through agricultural products to some provinces in South China, like Shanghai, Zhejiang and Guangdong, which are the densely populated and highly developed areas of the country. As one of the major bases for wheat and maize production in China, the export of these crops is the major component of agricultural virtual water outflow from the 3H region. However, the agricultural virtual water outflow in the 3H region is far less than the inflow, making the region a net receiver rather than a provider of agricultural virtual water.

Compared with the agricultural products, the total volume of interregional virtual water trade of the other four categories is about 2.8 billion m^3/year, much smaller than the agricultural category. A closer investigation found that virtual water exchanges between the 3H region with the northwestern provinces are mainly via agricultural products, while the virtual water trades of the other four categories dominantly occurs in the trade with the southern provinces. For the Mining category, only the trade between the 3H region and Jiangsu is noticeable. The 3H region is net exporting virtual water of mining products to Jiangsu by 0.16 billion m^3/year, of which 0.11 billion m^3 /year is from the mining of metal minerals. The 3H region is a net receiver of virtual water of manufacturing products in the interregional trade, with Fujian, Guangdong and Jiangsu as its main providers. The net virtual water exports of the manufacturing products from these provinces to the 3H region are 0.39 billion m^3/year, 0.27 billion m^3/year, 0.19 billion m^3/year, respectively. The 3H region is closely connected with its surrounding provinces via virtual water of supply of power, water & construction, with Inner Mongolia as its main provider, followed by Shanxi. As for the virtual water of service, the interconnections between the 3H regions and other provinces are relatively weak.

Concerning the international trade, the total net virtual export from the 3H region to other countries are 16.4 billon m^3/year, which is composed of 11.7 billon m^3/year of manufacturing virtual water, 1.97 billion m^3 /year of agricultural virtual water, 1.85 billon m^3/year of virtual water from the service category, 0.84 billion m^3/year of virtual water of mining products, and 0.04 billion m^3/year of virtual water of supply of power, water & construction.

Table 2 Interregional and International virtual water flow of the 3H region at the sectoral level (unit: 10^6 m^3/year)

Sector types	Sectors			Net virtual water import	
				interregional	international
Agriculture	1	AGR	Agriculture	13128	-1595
	2	FRT	Forestry	104	-1
	3	AMH	Animal husbandry	1412	-262
	4	FSR	Fishery	1994	-116
	Sub-total			**16638**	**-1974**
Mining industry	5	CMD	Coal mining and dressing	125	-348
	6	PGE	Petroleum and natural gas extraction	47	-14
	7	MMD	Metal minerals mining and dressing	-329	-421
	8	NMD	Nonmetal minerals mining and dressing	-29	-59
	Sub-total			**-186**	**-843**
Manufacturing industry	9	FDP	Food processing	-3	-3263
	10	TWL	Manufacture of textile wearing apparel and leather	29	-5171
	11	PTF	Processing of timber and manufacture of furniture	2	-149
	12	PPP	Manufacture of paper and paper products	174	-497
	13	PPC	Processing of petroleum and coking	107	-16
	14	CMP	Manufacture of raw chemical materials and chemical products	530	-1011
	15	NMP	Manufacture of non-metallic mineral products	-76	-499
	16	SPM	Smelting, pressing of metals	83	-312
	17	MPD	Metal products	18	-396
	18	MSM	Manufacture of special purpose machinery	30	-412
	19	TPE	Manufacture of transport equipment	35	191

	20	EME	Manufacture of electrical machinery and equipment	42	-11
	21	CCE	Manufacture of communication equipment, computers and other electronic equipment	66	-122
	22	OMS	Other manufacturing sectors	2	-28
	Sub-total			**1038**	**-11695**
Supply of power, water & Construction	23	EHP	Production and supply of electric power and heat power	1485	-11
	24	PSG	Production and supply of Gas	1	-6
	25	PSW	Production and supply of water	4	0
	26	CTR	Construction	2	-22
	Sub-total			**1492**	**-38**
Services	27	FTS	freight transport and storage	184	-239
	28	CTC	Commerce, tourism and catering services.	151	-1700
	29	OSV	Other services	115	93
	Sub-total			**449**	**-1847**

3.2 The water supply-demand balance in the 3H region

The water footprint of a region refers to the water needed for the production of the goods and services consumed by the inhabitants of the region (Hoekstra and Chapagain, 2007). Water footprint depicts a region’s actual water demand under certain economic level and consumption mode. It consists of the use of local water resources and the use of external water resources (i.e., external water footprint through virtual water trade). The water footprint, virtual water flows and water transfer through SNWT project of the 3H region are shown in Table 3. The total water footprint of the 3H region is 72 billion m^3/year. Henan is the province of the largest population and has the highest water footprint of 28.9 billion m^3/year, accounting for 40% of the 3H region.

As aforementioned, there are two sorts of external water supplement impacting regional water resources condition: one is the virtual water import accompanied with interregional/international trade of goods and services; the other is the real water transfer brought about by the SNWD project. The 3H region has a virtual water import of 60.8 billion m^3/year and virtual water export of 57.8 billion m^3/year, making it as a whole a net virtual water receiver of 3 billion m^3/year. This amount is much lower than the water supplement from the SNWD project (Table 3). However, for certain individual provinces within the 3H region, virtual water import functions as a significant water supplement. For instance, In Beijing, Tianjin and Henan, their net virtual water imports are equivalent or even far exceeding the amount of water transfer through SNWD project. On the contrary, Hebei loses 7 billion m^3/year of virtual water, far outweighing its gain from real water transfer from SNWD project, making its total water supplement negative. This worsens its already severe water scarce condition. Shandong is the other region of a negative external water supplement, but its situation is less serious since its water loss is minor and its conflict between water supply and demand are milder than Hebei.

Table 3. Water footprint, virtual water flows and water transfer through the SNWD project (unit: 10^6 m^3/year)

Regions/provinces	Water footprint	International and interregional trade of virtual water		Net virtual water import	Water supply from the SNWTP*
		Virtual water import	Virtual water export		
	A	B	C	B-C	D
The 3H region	**71986**	**60849**	**57814**	**3035**	**10853**
Beijing	6178	5763	3067	2697	1240
Tianjin	3370	3510	2477	1033	1020
Hebei	13247	7622	14625	-7003	3470
Shandong	20294	25685	27346	-1661	1353
Henan	28898	18270	10300	7970	3770

** Refers to the water transferred in the Phase I of East and Middle route (to be finished in 2014).*

4. Discussion and implications

4.1. The role of virtual water trade and real water transfer from SNWD project

The composition of the water exchange of the 3H region, including the real water and the virtual water, is demonstrated as Figure 4. Regarding the 3H region as a whole, its water gains from outside are accomplished in three ways: the real water transfer from the SNWD project, the virtual water import of agricultural products and the virtual water import of the supply of power, water & construction. Virtual water of the agricultural products functions as a substantial component of the water supplement. Except for Hebei, the other four provinces in the 3H region all gain virtual water from trade of agricultural products, including the traditionally acknowledged agricultural provinces Shandong and Henan. Although these provinces are also supplying virtual water via agricultural products, the amount is offset by the larger amount of inflow, making these provinces as a whole net virtual water receivers from agricultural products. The large amount of virtual water inflow of agricultural products is relevant to the growth in the demand for agricultural products in the 3H region, including the final demand of the domestic residents as well as the intermediate demand of the down-stream industries using the agricultural products as raw materials (e.g. food processing and manufacturing) (Shi and Zhang, 2012; Shi, et al., 2013). The virtual water of agricultural products flowing into Shandong is mainly from Heilongjiang, Inner Mongolia and Guangxi, while the inflow to Henan is mainly from Hunan, Sichuan and Guangxi.

Although the scale is still lower than the virtual water, the function of real water transfer from SNWD project as a source of water supplement is significant. Especially for Hebei, where the virtual water is predominantly outflowing, the real water transfer is crucial in maintaining its social and economic development. With the economic development and the population growth, the gap between water supply and demand in the 3H region tends to enlarge. The role of real water in alleviating water pressure will be further strengthened along with the completion of all the phases of the SNWD project. Although there are numerous debates on the possible negative impacts brought about by the project, its positive role as a significant water supplement is undeniable.

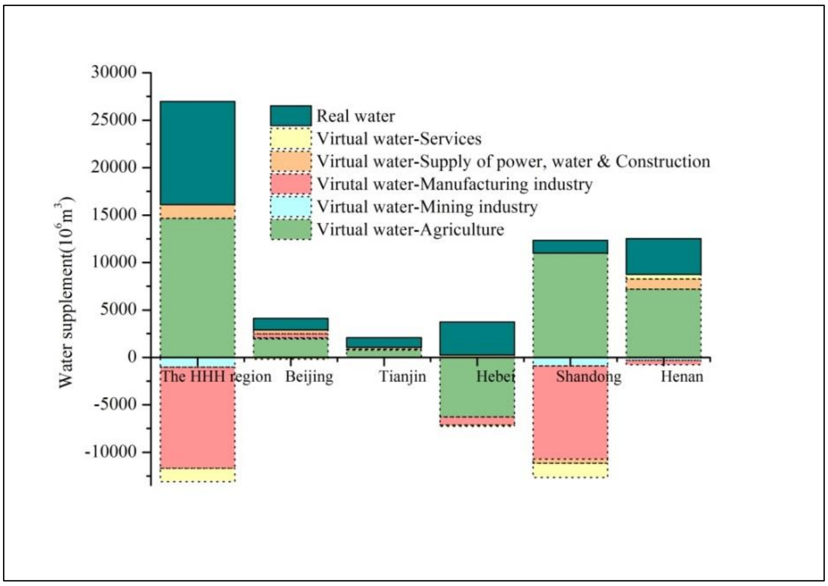

Figure 4. The composition of the water supplement/loss for the 3H region

4.2 The 3H region's role as the 'breadbasket' of the nation

Agricultural is the biggest water user in the 3H region, about 63.5% of the withdrawal water is for irrigation (NBSC, 2013.). The virtual water export is also the largest in the all the economic sectors, despite the overall net import of virtual water in the agricultural sector (Table 2). One way to alleviate the pressure on the local water resources would be to increase the import of agricultural products from outside and reduce the virtual water export from agriculture products, e.g., wheat and maize. However, this has not been the trend in the last 10 years in the region.

Table 4 Changes in the wheat and corn sown areas and production in the 3H region

Region/ Provinces	Wheat 2002-2012				Maize 2002-2012			
	2002-2007		2007-2012		2002-2007		2007-2012	
	Change in sown areas	Change in production	Change in sown areas	Change in production	Change in sown areas	Change in production	Change in sown areas	Change in production
	1000 ha	10000 ton	1000 ha	10000 ton	1000 ha	10000 ton	1000 ha	10000 ton
Beijing	-6.05	-3.91	10.85	7.06	51.79	30.44	-6.97	7.04
Tianjin	8.95	6.48	8.27	5.17	15.73	14.03	17.15	7.37
Hebei	-37.21	94.17	-2.42	144.03	285.15	386.84	186.56	227.71

Shandong	121.60	448.51	106.79	183.93	324.16	500.45	163.83	178.03
Henan	357.63	731.82	126.67	197.14	459.32	392.77	320.78	165.22
The 3H region	**444.92**	**1277.07**	**250.16**	**537.33**	**1136.15**	**1324.53**	**681.35**	**585.37**
Nation	**-187.69**	**1900.80**	**547.66**	**1172.52**	**4843.80**	**3099.29**	**5552.31**	**5331.36**
% of the 3H region in the nation		**67%**	**46%**	**46%**	**23%**	**43%**	**12%**	**11%**

Data source: NSBC, 2003-2013.

Table 4 shows the changes in sown area and production of the wheat and maize in the 3H region. During 2002-2007, the sown area of wheat in the 3H region increased by 444.92 thousand ha, in contrast to an overall decreasing tendency of the whole country. The increase in wheat production in the 3H region accounted for 67% of the nation total increase. The trend of expansion in wheat sown area and production continued in the later years. During 2007-2012, the increases in wheat sown areas and production accounted for 46% of the total increases of the national total. Similar to wheat, the sown area and production of the maize also experience a significant expansion. During 2002-2007, the increase in maize sown area and production accounted for 23% and 43% of the nation total increase, respectively. During 2007-2012, the increasing trend continued although the speed slowed down. The situation suggests that the 3H region's role as the main provider for wheat and maize has not changed but continuously strengthened despite the severe water shortage.

Given the non-substitutable favorable climate conditions for wheat and maize in the 3H region, the important role of the region for supplying wheat and maize is unlikely to change in the future. Facing the exacerbating water crisis, the fundamental way for the 3H region to reduce agricultural water use is to improve irrigation water use efficiency. Currently there is still plenty of room for the improvement. The average irrigation water use efficiency, the portion of crop evaporation to total irrigation water supply, in the 3H region is around 0.5, compared with over 0.7 in the developed countries like Israel, America, Canada, etc. (Wang et al., 2009). The improved agronomic measures like soil water management, irrigation system innovation, water-saving facility application, etc. can effectively increase the irrigation water use efficiency. The water thrifty agriculture will be the direction for the 3H region to pursue.

4.3 Position of the individual provinces of the 3H region in coping with water crisis

Results of this study indicate that the virtual water inflows accompanied with trade are in favor of alleviating the water pressure of the 3H region. If simply judging from the perspective of the 3H region, virtual water import can be an effective way to alleviate water scarcity for the region. However, currently the region's use of external virtual water is rather small, indicated by the small percentage of external net virtual water import (Table 3). Therefore, in the long run, it is important for the 3H region to restructure its industries. Given the provinces inside the 3H region is currently at different phases of industrial development and have distinguishing roles in the national development, the industrial restructuring strategies should be tailored with differentiation. For Beijing and Tianjin, the technology intensive industries which are also water-saving industries should be continuously supported and gradually become the leading industries of the cities. Its traditional agriculture should be converted to the metropolitan agriculture, with the water intensive and low market value crops gradually moving out of the cities. The residential needs for agricultural products should predominantly depend on external supply rather than local production in the future. In other words, there should be more virtual water of agricultural products flowing into Beijing and Tianjin in the future. Shandong is the principle virtual water exporter for the manufacturing products. Its manufacturing industry needs to be developed toward innovation oriented industries. In the meantime, Shandong has to carry on the role as agricultural virtual water provider to Beijing and Tianjin. Another two agricultural virtual water providers inside the 3H region are Hebei and Henan, which are at the relatively lower stage of the industrialization ladder. It should be noted that some industries are departing from the nearby developed provinces (e.g.

Beijing, Jiangsu) due to the constraint of labor cost, land over-demand, water scarcity, etc. In this context, Hebei and Henan are expected to seize the opportunity to realize their manufacturing industry upgrading.

5. Summary

Interregional water movement can be realized by real water transfers through massive engineering projects and/or by virtual water transfers in form of commodity trade. This study demonstrates the general pattern of the interregional water transfer in the two forms in the 3H region as well as their roles in impacting regional water security. Some enlightenments on the 3H region's future practices in dealing with water scarcity are drawn. The main findings include:

- The 3H region as a whole is receiving a relatively small amount of net virtual water from outside, with its virtual water inflow from other provinces dominated by agricultural sectors and virtual water export to other countries dominated by manufacturing sectors.
- Both virtual water trade and real water transfer from SNWD project are important water supplements in alleviating the water pressure in the 3H region. The role of the real water transfer as a water supplement is expected to be strengthened with the completion of the subsequent stages of the SNWD project.
- Despite the water scarcity, the 3H region will maintain its status as the major producer of wheat and maize due to its non-substitutable favorable climate conditions for these crops. Improving irrigation water use efficiency of wheat and maize production will be the effective way to control the irrigation water use in the 3H region.
- In the long run, the way for the 3H region out of its water crisis lies in internal industrial structure upgrading with the individual provinces taking differentiated roles compatible with their different development phases.

It should be noted that this study is a preliminary attempt to integrate virtual water and real water in regional water resources investigation. A further step to advance the study would be a quantitative investigation of the impacts of constraints of water resource on regional economic growth and industrial restructure, which would provide more comprehensive information to deepen our understanding of the relationship between water resources and regional development.

Acknowledgement

This work was supported by National Natural Science Foundation of China under Grant No. 71303232 and Grant No. 71173212.

Appendix A. The specific results of the DWUCs of the 29 sectors ($m^3/10^4$Yuan)

Sectors		Beijing	Tianjin	Hebei	Shanxi	Inner Mongolia	Liaoning	Jilin	Heilongjiang	Shanghai	Jiangsu
1	AGR	807	729	797	997	2064	779	1149	2383	649	1564
2	FRT	47	42	46	58	119	45	67	138	38	91
3	AMH	468	423	462	579	1198	452	667	1383	377	908
4	FSR	686	619	677	847	1754	662	976	2025	552	1329
5	CMD	5	4	7	10	13	10	9	14	15	13
6	PGE	3	3	4	6	8	6	6	9	9	8
7	MMD	10	10	16	22	29	22	20	31	32	29
8	NMD	3	3	5	7	9	7	6	10	10	9
9	FDP	6	5	9	13	17	13	11	18	19	17
10	TWL	2	2	3	5	6	5	4	7	7	6
11	PTF	1	1	2	2	3	2	2	3	4	3
12	PPP	12	11	19	26	35	26	24	37	39	35
13	PPC	4	3	6	8	10	8	7	11	12	10
14	CMP	7	6	10	14	18	14	12	20	20	18
15	NMP	4	4	7	9	12	9	8	13	13	12
16	SPM	5	4	7	10	13	10	9	14	15	13
17	MPD	1	1	1	1	2	1	1	2	2	2
18	MSM	1	1	1	1	2	1	1	2	2	2
19	TPE	1	1	2	2	3	2	2	3	3	3
20	EME	1	1	1	2	3	2	2	3	3	3
21	CCE	1	1	1	1	2	1	1	2	2	2
22	OMS	0	0	1	1	1	1	1	1	1	1
23	EHP	38	35	58	81	106	81	73	115	119	108
24	PSG	1	1	2	2	3	2	2	4	4	3
25	PSW	5	5	8	11	14	11	10	15	16	14
26	CTR	1	1	1	2	3	2	2	3	3	3
27	FTS	7	13	13	16	20	16	13	14	9	13
28	CTC	4	7	7	9	11	9	7	8	5	7
29	OSV	5	9	10	12	14	12	9	10	7	9

Sectors		Zhejiang	Anhui	Fujian	Jiangxi	Shandong	Henan	Hubei	Hunan	Guangdong	Guangxi
1	AGR	874	1214	1186	2084	382	520	1353	1753	534	2030
2	FRT	51	70	69	121	22	30	78	101	31	118
3	AMH	507	704	688	1210	221	302	785	1017	310	1178
4	FSR	742	1031	1008	1771	324	442	1150	1490	454	1725
5	CMD	14	14	16	17	10	9	12	16	16	15
6	PGE	9	9	10	11	6	5	7	10	10	9
7	MMD	31	31	34	37	22	19	25	35	36	33
8	NMD	10	10	11	12	7	6	8	11	11	11
9	FDP	18	18	20	21	13	11	15	20	21	19
10	TWL	7	7	7	8	5	4	6	8	8	7
11	PTF	3	3	4	4	2	2	3	4	4	4
12	PPP	37	37	41	44	26	22	30	41	43	40
13	PPC	11	11	12	13	8	7	9	12	13	12
14	CMP	19	20	21	23	14	12	16	22	22	21
15	NMP	13	13	14	15	9	8	11	14	15	14
16	SPM	14	14	15	17	10	8	12	16	16	15
17	MPD	2	2	2	2	1	1	2	2	2	2
18	MSM	2	2	2	2	1	1	2	2	2	2
19	TPE	3	3	3	4	2	2	2	3	3	3
20	EME	3	3	3	3	2	2	2	3	3	3
21	CCE	2	2	2	2	1	1	2	2	2	2
22	OMS	1	1	1	1	1	1	1	1	1	1
23	EHP	114	115	125	137	81	68	94	127	131	123
24	PSG	4	4	4	4	2	2	3	4	4	4
25	PSW	15	15	16	18	11	9	12	17	17	16
26	CTR	3	3	3	3	2	2	2	3	3	3
27	FTS	16	19	18	14	16	9	18	15	13	12
28	CTC	9	11	10	8	9	5	10	8	7	6
29	OSV	12	14	13	10	12	7	13	11	9	8

Sectors		Hainan	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Xinjiang
1	AGR	1017	542	950	1483	1394	850	1408	2092	2545	2881
2	FRT	59	31	55	86	81	49	81	121	147	167
3	AMH	590	314	552	861	809	493	817	1214	1477	1672
4	FSR	864	460	808	1261	1184	722	1196	1778	2163	2449
5	CMD	18	17	18	17	18	13	16	17	13	19
6	PGE	11	10	11	10	11	8	10	11	8	11
7	MMD	39	36	38	36	39	29	35	37	28	40
8	NMD	12	12	12	12	12	9	11	12	9	13
9	FDP	22	21	22	21	22	17	20	21	16	23
10	TWL	8	8	8	8	9	6	8	8	6	9
11	PTF	4	4	4	4	4	3	4	4	3	4
12	PPP	47	43	46	43	47	34	42	45	33	48
13	PPC	14	13	14	13	14	10	12	13	10	14
14	CMP	24	23	24	23	24	18	22	23	17	25

15	NMP	16	15	16	15	16	12	14	15	12	17
16	SPM	18	16	17	16	18	13	16	17	13	18
17	MPD	2	2	2	2	2	2	2	2	2	2
18	MSM	2	2	2	2	2	2	2	2	2	2
19	TPE	4	4	4	4	4	3	3	4	3	4
20	EME	4	3	4	3	4	3	3	3	3	4
21	CCE	2	2	2	2	2	2	2	2	2	2
22	OMS	1	1	1	1	1	1	1	1	1	1
23	EHP	143	133	141	133	144	106	128	137	102	148
24	PSG	4	4	4	4	4	3	4	4	3	5
25	PSW	19	17	18	17	19	14	17	18	13	19
26	CTR	4	3	4	3	4	3	3	3	3	4
27	FTS	19	16	19	16	17	15	17	16	17	16
28	CTC	10	9	11	9	10	8	10	9	10	9
29	OSV	14	11	14	12	13	11	13	12	13	12

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